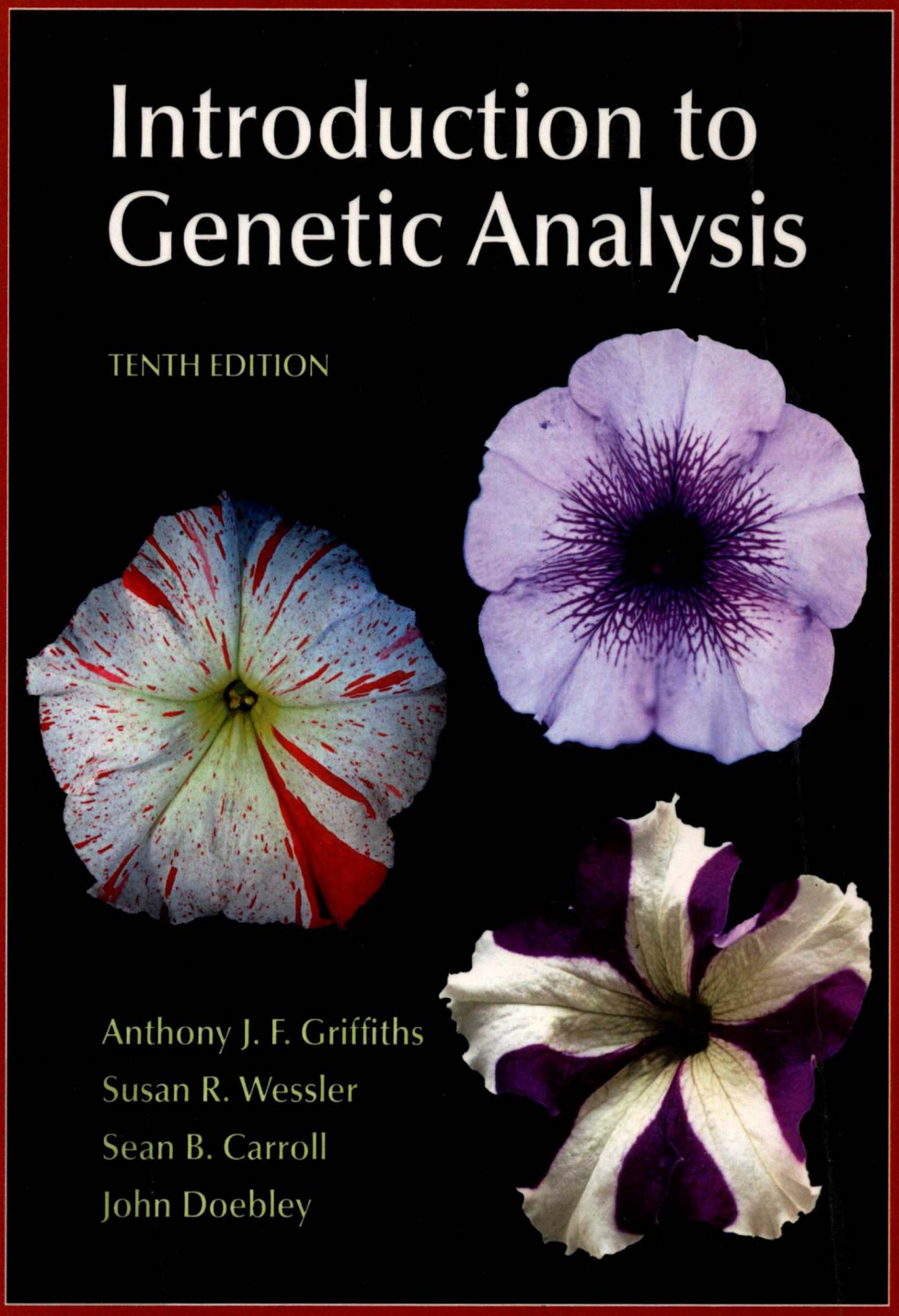
Preliminary Solutions Manual



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Solutions Manual
For
Introduction to Genetic Analysis
Tenth Edition

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The Genetics Revolution in the Life Sciences

PROBLEMS

In each chapter, a set of problems tests the reader's comprehension of the concepts in the chapter and their relation to concepts in previous chapters. Each problem set begins with some problems based on the figures in the chapter, which embody important concepts. These are followed by problems of a more general nature.

WORKING WITH THE FIGURES

1. In considering Figure 1-2, if you were to extend the diagram, what would the next two stages of "magnification" beyond DNA be?

Answer: The next stage of the diagram would be an in-depth look into the DNA molecule, as two long molecular strands of nucleotides wound around each other in a double helix and the basic structure of those monomers. Focus on specific nucleotides and their organic molecule parts: a deoxyribose sugar, a phosphate group, and a nitrogenous base (adenine, thymine, guanine, and cytosine). Second, would be atomic composition of those organic molecules (C, H, O, P, and N).

2. In considering Figure 1-3,

a. what do the small blue spheres represent?
b. what do the brown slabs represent?
c. do you agree with the analogy that DNA is structured like a ladder?

Answer:
a. Blue ribbon represents sugar phosphate backbone (deoxyribose and a phosphate group), while the blue spheres signify atoms.
b. Brown slabs show complementary bases (A, T, G, and C)
c. Yes, it is a helical structure.

3. In Figure 1-4, can you tell if the number of hydrogen bonds between adenine and thymine is the same as that between cytosine and guanine? Do you think that a DNA molecule with a high content of A + T would be more stable than one with high content of G + C?

Answer: There are two hydrogen bonds between adenine and thymine; three between guanine and cytosine. No, the molecule with a high content of G-C would be more stable.

4. From Figure 1-6, can you predict how many chromosomes there would be in a muntjac sperm? How many purple chromosomes would there be in a sperm cell?

Answer: There would be only three chromosomes in a sperm cell of this species. Since each homologous chromosome pair is stained with a different color, there would be only one purple chromosome in a sperm cell.

5. In examining Figure 1-7, state one major difference between the chromosomal "landscapes" of yeast and *Drosophila*.

Answer: Yeast chromosome landscape shows fewer introns and less space between the coding genes.

6. In Figure 1-8, is it true that the direction of transcription is from right to left as written for all the genes shown in these chromosomal segments?

Answer: No, there is one gene that would be read from left to right, since RNA polymerase can assemble polynucleotides only in the 5′ -3′ direction.

7. In Figure 1-9, estimate what length of DNA is shown in the right-hand part of the figure.

Answer: The right-hand part of this figure shows a section of a 30 nm fiber, which is composed of nucleosomes (10 nm fibers) DNA alone is a 2 nm fiber. If stretched out, a DNA molecule of each chromosome would be about 4 cm long, thousands of times the diameter of a cell nucleus.

8. From Figure 1-12, what is the main difference in the locales of transcription and translation?

Answer: In a eukaryotic cell the nucleus provides a separate location for

transcription, while translation continues in the cell cytoplasm.

9. In Figure 1-14, what do the colors blue and gold represent?

Answer: Blue represents original DNA (chromatid) in a cell before replication, while gold represents new DNA (sister chromatids) after the semi-conservative replication of the chromosome.

10. From Figure 1-17, locate the chromosomal positions of three genes involved in tumor production in the human body.

Answer: There are many genes involved in tumor production in humans, such as a gene for: neurofibromatosis on chromosome 2, familial colon cancer on chromosome 2, for malignant melanoma on chromosome 9, and retinoblastoma on chromosome 13.

11. In Figure 1-18, calculate the approximate number of nucleotide differences between humans and dogs in the cytochrome *c* gene. Repeat for humans and moths. Considering that the gene is several hundred nucleotides long, do these numbers seem large or small to you? Explain.

Answer: Cytochrome *c* appears somewhat different when compared between humans and dogs, since they diverged with approximately 14 nucleotide substitutions since the common ancestor. Humans and moths differ even more, in about 32 nucleotide substitutions, yet the difference is not as large as expected based on the broad biological differences between insects and mammals. These could tell us that the cytochrome *c* gene has been highly conserved due to its significance in metabolism of aerobic organisms.

12. In Figure 1-21, why are colored ladders of bands shown in all three electrophoretic gels? If the molecular labels used in all cases were radioactive, do you think the black bands in the bottom part of the figure would all be radioactive?

Answer: In this figure we see three different types of electrophoresis in different colors (Southern blot of DNA fragments, Northern blot of RNA and Western blot of a protein product). Such a mixture of macromolecules could be hybridized with a radioactive probe, and the bands in the lower part of the figure would indicate radioactivity.

BASIC QUESTIONS

13. In this chapter, the statement is made that most of the major questions of biology have been answered through genetics. What are the main questions of biology, and do you agree with the above statement? (State your reasons.)

Answer: Biological sciences inquire about life and its properties. Many themes connect concepts and study life's properties at the different levels of biological hierarchy. One main theme is the continuity of life, which is based on heredity. Genetics studies this theme in a great detail. Another theme is of course, evolution of life, where again genetics plays a major role in understanding life history and unity, as well as diversity of life.

14. It has been said that the DNA → RNA → protein discovery was the "Rosetta stone" of biology. Do you agree?

Answer: Yes, this is the main aspect of the information processing in a cell: from DNA to RNA and protein; from genotype to phenotype. Although this has been a "central dogma of molecular biology" for decades, we know today that it has its exceptions, such as the reverse transcription (RNA viruses) or the small RNA and their role in gene regulation.
Understanding of this essential concept of life gives us an insight into another, such as evolution, and the nature of mutations as a basic source of variability upon which evolutionary processes might act.

15. Who do you think had the greatest impact on biology, Charles Darwin or the research partners James Watson and Francis Crick?

Answer: Charles Darwin made an enormous impact on Biological sciences and society, and his works are studied in many different areas, continuing to make an impact today. A hundred years later, James Watson and Francis Crick discovered the double helix, a molecule of life's heritable information. This was perhaps the most significant milestone in genetics and beyond. If Darwin had any information about genes, even more about the properties of life's blueprints, his theory would have an important mechanism. It was the scientists of the first half of the twentieth century who made a connection between the works of Darwin and Mendel in the "great synthesis" and those in the second half of the twentieth century who made a connection of all these milestones in the field of molecular evolution. Today, in the twenty-first century both themes grew into studies of genomes and phylogenies and at the even higher level into integrative and systems biology. It is hard to say whose contribution is greater, but we must see their presence in the entire realm of the biological sciences.

16. How has genetics affected (a) agriculture, (b) medicine, (c) evolution, and (d) modern biological research?

Answer:

a. Genetics has affected agriculture for thousands of years, yet since the early twentieth century this impact has been essential. Knowledge of the genetic basis of traits and the experimental crossing allowed the growth in all of the fields of agriculture. Besides artificial selection and breeding strategies, recombinant DNA technology lead to genetic engineering and amazing results in this filed.

b. One of the fastest growing areas of genetics is the area involved with human health and medicine. Genetics plays an essential role in studies of many diseases, such as numerous hereditary diseases, cancer, diabetes, etc. Many genetic disciplines are constantly involved in such studies and practices to understand and diagnose human diseases. In addition, genetics plays an essential role in reproductive biology. Finally, genetics might be used to cure diseases, whether through gene therapy, stem cell treatments, or pharmacogenomics.

c. Evolution could be defined as a change in genetic makeup of a population over time or, at a more broad level in Darwin's words, as a descent with modification. In the light of modern genetics, we could see how changes in genomes support the concept that all of the living species descend from ancestral species. Evolution is supported by an extensive amount of evidence, above all genetic evidence, which continues to enrich our understanding of life's unity and diversity. For example, phylogenies constructed on genetic studies of species show evolutionary relationships, enabling scientists to construct the tree of life. Besides such studies based on genetics, studies in population, quantitative and developmental genetics, molecular genetics, and bioinformatics bring new insights on evolution as a unifying theory of all biology.

d. Genetics is the essential discipline in modern biological research and it is present in almost every field of study. DNA cloning and polymerase chain reaction techniques changed the way modern biology operates. At the same time, DNA technology allows us to find genes of interest and study their function. Reproductive cloning of mammals, genetic engineering, forensics, stem cell research, diagnosis of human diseases, and gene therapy are new areas in modern biology founded on genetics.

17. Assume for the sake of this question that the human body contains a trillion cells (a low estimate). We know that a human genome contains about 1 meter of DNA. If all the DNA in your body were laid end to end, do you think it could stretch to the Moon and back? Justify your answer with a calculation. (**Note:** The average distance to the Moon is 385,000 kilometers.)

Answer: Yes, if we could take DNA molecules from all of the nuclei in an individual human and lay them straight, one after another, a total length of such nucleic acid polymer would be equal: number of cells in a human body (trillion or 1,000,000,000,000) × length of each cell's DNA (1 m or 0.001 km) = 1,000,000,000 km, enough to reach the Moon and return. The key to such enormous lengths is the chromosome packaging.

2

Single Gene Inheritance

WORKING WITH THE FIGURES

(The first 14 questions require inspection of text figures.)

1. In the left-hand part of Figure 2-4, the red arrows show selfing as pollination within single flowers of one F_1 plant. Would the same F_2 results be produced by cross-pollinating two different F_1 plants?

Answer: No, the results would be different. While self pollination produces 3 : 1 ratio of yellow versus gene phenotype, cross pollination would result in 1 : 1 ratio, in the F_2. This is because F_1 yellow are heterozygous, while green are homozygous genotypes.

2. In the right-hand part of Figure 2-4, in the plant showing an 11 : 11 ratio, do you think it would be possible to find a pod with all yellow peas? All green? Explain.

Answer: Yes, it is possible to find a pod with only yellow peas or heterozygous for the seed color gene, if all the flowers had dominant allele in a given fruit/pod. This could be also one example of rare changes at a physiological level.

3. In Table 2-1, state the recessive phenotype in each of the seven cases.

Answer: wrinkled seeds; green seeds; white petals; pinched pods; yellow pods; terminal flowers; short stems

4. Considering Figure 2-8, is the sequence "pairing → replication → segregation → segregation" a good shorthand description of meiosis?

Answer: No, it should say either: "pairing, recombination, segregation, segregation" or: "replication, pairing, segregation, segregation."

5. Point to all cases of bivalents, dyads, and tetrads in Figure 2-11.

Answer: Replicate sister chromosomes or dyads are at any chromatid after the replication (S phase). A pair of synapsed dyads is called a bivalent and it would represent two dyads together (sister chromatids on the right), while the four chromatids that make up a bivalent are called a tetrad and they would be the entire square (with same or different alleles on the bivalents).

6. In Figure 2-12, assume (as in corn plants) that A encodes an allele that produces starch in pollen and allele a does not. Iodine solution stains starch black. How would you demonstrate Mendel's first law directly with such a system?

Answer: One would use this iodine dye to color the starch producing corn pollen. Since pollen is a plant gametophyte generation (haploid) it will be produced by meiosis. Mendel's first law predicts segregation of alleles into gametes, therefore we would expect 1 : 1 ratio of starch producing (A) versus non-starch producing (a) pollen grains, from a heterozygous (A/a) parent/male flower. It would be easy to color the pollen and count the observed ratio.

7. In the text figure on page 43, assume the left-hand individual is selfed. What pattern of radioactive bands would you see in a Southern analysis of the progeny?

Answer: If an individual is selfed, the restriction fragments should be identical to the parents fragments. In this case, a heterozygous parent to the left had three bands (two from a mutant allele "a" and one from dominant allele "A").

8. Considering Figure 2-15, if you had a homozygous double mutant *m3*/*m3* *m5*/*m5*, would you expect it to be mutant in phenotype? (**Note**: This line would have two mutant sites in the same coding sequence.)

Answer: Yes, this double mutant *m3*/*m3* and *m5*/*m5* would be a null mutation, because *m3* mutation changes the exon sequence.

9. In which of the stages of the *Drosophila* life cycle (represented in the box on page 52) does meiosis take place?

Answer: Meiosis happens in adult ovaries and testes, therefore before fertilization. After fertilization, fruit flies would lay their eggs (with now diploid embryos). That would be Stage 1 on the figure.

10. If you assume Figure 2-17 also applies to mice and you irradiate male sperm with X rays (known to inactivate genes), what phenotype would you look for in progeny in order to find cases of individuals with an inactivated *SRY* gene?

Answer: If we inactivate the *SRY* gene in mammals with radiation, the offspring should all be phenotypically females, yet on the chromosome level there would be both XX and XY (in this case sterile, female looking males).

11. In Figure 2-19, how does the 3 : 1 ratio in the bottom-left-hand grid differ from the 3 : 1 ratios obtained by Mendel?

Answer: It differs because in Mendel's experiments, we learned about autosomal genes, while in this case we have a sex linked gene for eye color.
3 : 1 ratio means that all females have red eyes ($X^{+/-}$), while half the males have red (X^{+}/Y) and half white (X^{W}/Y).
Careful sex determination when counting F_2 offspring would point out to a sex linked trait.

12. In Figure 2-21, assume that the pedigree is for mice, in which any chosen cross can be made. If you bred IV-1 with IV-3, what is the probability that the first baby will show the recessive phenotype?

Answer: The answer would be:
2/3 x 2/3 x 1/4 = 1/9 or 0.11

Probability that IV 1 and IV 3 mice are heterozygous is 2/3. This is because both of their parents are known heterozygotes (*A*/*a*) and since they are dominant phenotype they could only be A/A or A/a. Now, probability that two heterozygotes have a recessive homozygote offspring is 1/4.

13. Which part of the pedigree in Figure 2-23 in your opinion best demonstrates Mendel's first law?

Answer: Any part of this pedigree demonstrates the law, showing segregation of alleles into gametes. The middle part of generation II marriage shows a typical test cross (expected 1:1). Neither ratio in the pedigree could be confirmed because of a small sample size in any given family, but allele segregation is obvious.

14. Could the pedigree in Figure 2-31 be explained as an autosomal dominant disorder? Explain.

Answer: Yes, it could in some cases, but in this case we have clues that the pedigree is for a sex linked dominant trait. First, if fathers have a gene, daughters will receive it only, and second, if mother has a gene, both sons and daughters would receive it.

BASIC PROBLEMS

15. Make up a sentence including the words *chromosome, genes,* and *genome.*

Answer: The human genome contains an estimated 20,000–25,000 genes located on 23 different chromosomes.

16. Peas (*Pisum sativum*) are diploid and $2n = 14$. In *Neurospora,* the haploid fungus, $n = 7$. If it were possible to fractionate genomic DNA from both species by using pulsed field electrophoresis, how many distinct DNA bands would be visible in each species?

Answer: PFGE separates DNA molecules by size. When DNA is carefully isolated from *Neurospora* (which has seven different chromosomes) seven bands should be produced using this technique. Similarly, the pea has seven different chromosomes and will produce seven bands (homologous chromosomes will co-migrate as a single band).

17. The broad bean (*Vicia faba*) is diploid and $2n = 18$. Each haploid chromosome set contains approximately 4 m of DNA. The average size of each chromosome during metaphase of mitosis is 13 μm. What is the average packing ratio of DNA at metaphase? (Packing ratio = length of chromosome/length of DNA molecule therein.) How is this packing achieved?

Answer: There is a total of 4 m of DNA and nine chromosomes per haploid set. On average, each is $^4/_9$ m long. At metaphase, their average length is 13 μm, so the average packing ratio is 13×10^{-6} m : 4.4×10^{-1} m or roughly 1 : 34,000! This remarkable achievement is accomplished through the interaction of the DNA with proteins. At its most basic, eukaryotic DNA is associated with histones in units called nucleosomes and during mitosis, coils into a solenoid. As loops, it associates with and winds into a central core of nonhistone protein called the scaffold.

18. If we call the amount of DNA per genome "x," name a situation or situations in diploid organisms in which the amount of DNA per cell is:

a. x **b.** $2x$ **c.** $4x$

Answer: Because the DNA levels vary four-fold, the range covers cells that are haploid (gametes) to cells that are dividing (after DNA has replicated but prior to cell division). The following cells would fit the DNA measurements:

x^+	haploid cells
$2x$	diploid cells in G_1 or cells after meiosis I but prior to meiosis II
$4x$	diploid cells after S but prior to cell division

19. Name the key function of mitosis.

Answer: The key function of mitosis is to generate two daughter cells genetically identical to the original parent cell.

20. Name two key functions of meiosis.

Answer: Two key functions of meiosis are to halve the DNA content and to reshuffle the genetic content of the organism to generate genetic diversity among the progeny.

21. Can you design a different nuclear-division system that would achieve the same outcome as that of meiosis?

Answer: It's pretty hard to beat several billions of years of evolution, but it might be simpler if DNA did not replicate prior to meiosis. The same events responsible for halving the DNA and producing genetic diversity could be achieved in a single cell division if homologous chromosomes paired, recombined, randomly aligned during metaphase, and separated during anaphase, etc. However, you would lose the chance to check and repair DNA that replication allows.

22. In a possible future scenario, male fertility drops to zero, but, luckily, scientists develop a way for women to produce babies by virgin birth. Meiocytes are converted directly (without undergoing meiosis) into zygotes, which implant in the usual way. What would be the short- and long-term effects in such a society?

Answer: In large part, this question is asking, why sex? Parthenogenesis (the ability to reproduce without fertilization—in essence, cloning) is not common among multicellular organisms. Parthenogenesis occurs in some species of lizards and fishes, and several kinds of insects, but it is the only means of reproduction in only a few of these species. In plants, about 400 species can reproduce asexually by a process called apomixis. These plants produce seeds without fertilization. However, the majority of plants and animals reproduce

sexually. Sexual reproduction produces a wide variety of different offspring by forming new combinations of traits inherited from both the father and the mother. Despite the numerical advantages of asexual reproduction, most multicellular species that have adopted it as their only method of reproducing have become extinct. However, there is no agreed upon explanation of why the loss of sexual reproduction usually leads to early extinction or conversely, why sexual reproduction is associated with evolutionary success.

On the other hand, the immediate effects of such a scenario are obvious. All offspring will be genetically identical to their mothers, and males would be extinct within one generation.

23. In what ways does the second division of meiosis differ from mitosis?

Answer: As cells divide mitotically, each chromosome consists of identical sister chromatids that are separated to form genetically identical daughter cells. Although the second division of meiosis appears to be a similar process, the "sister" chromatids are likely to be different. Recombination during earlier meiotic stages has swapped regions of DNA between sister and nonsister chromosomes such that the two daughter cells of this division typically are not genetically identical.

24. Make up mnemonics for remembering the five stages of prophase I of meiosis and the four stages of mitosis.

Answer: The four stages of mitosis are: prophase, metaphase, anaphase, and telophase. The first letters, PMAT, can be remembered by a mnemonic such as: Playful Mice Analyze Twice.

The five stages of prophase I are: leptotene, zygotene, pachytene, diplotene, and diakinesis. The first letters, LZPDD, can be remembered by a mnemonic such as: Large Zoos Provide Dangerous Distractions.

25. In an attempt to simplify meiosis for the benefit of students, mad scientists develop a way of preventing premeiotic S phase and making do with having just one division, including pairing, crossing over, and segregation. Would this system work, and would the products of such a system differ from those of the present system?

Answer: Yes, it could work but certain DNA repair mechanisms (such as postreplication recombination repair) could not be invoked prior to cell division. There would be just two cells as products of this meiosis, rather than four.

26. Theodor Boveri said, "The nucleus doesn't divide; it is divided." What was he getting at?

Answer: The nucleus contains the genome and separates it from the cytoplasm. However, during cell division, the nuclear envelope dissociates (breaks down). It is the job of the microtubule-based spindle to actually separate the chromosomes (divide the genetic material) around which nuclei reform during telophase. In this sense, it can be viewed as a passive structure that is divided by the cell's cytoskeleton.

27. Francis Galton, a geneticist of the pre-Mendelian era, devised the principle that half of our genetic makeup is derived from each parent, one-quarter from each grandparent, one-eighth from each great-grandparent, and so forth. Was he right? Explain.

Answer: Yes, half of our genetic makeup is derived from each parent, each parent's genetic makeup is derived half from each of their parents, etc.

28. If children obtain half their genes from one parent and half from the other parent, why aren't siblings identical?

Answer: Because the "half" inherited is very random, the chances of receiving exactly the same half is vanishingly small. Ignoring recombination and focusing just on which chromosomes are inherited from one parent (for example, the one they inherited from their father or the one from their mother?), there are 2^{23} = 8,388,608 possible combinations!

29. State where cells divide mitotically and where they divide meiotically in a fern, a moss, a flowering plant, a pine tree, a mushroom, a frog, a butterfly, and a snail.

Answer:

	Mitosis	Meiosis
fern	sporophyte gametophyte	(sporangium)
moss	sporophyte gametophyte	sporophyte (antheridium and archegonium)
plant	sporophyte gametophyte	sporophyte (anther and ovule)
pine tree	sporophyte gametophyte	sporophyte (pine cone)
mushroom	sporophyte gametophyte	sporophyte (ascus or basidium)
frog	somatic cells	gonads
butterfly	somatic cells	gonads

snail	somatic cells	gonads

30. Human cells normally have 46 chromosomes. For each of the following stages, state the number of nuclear DNA molecules present in a human cell:

a. metaphase of mitosis.
b. metaphase I of meiosis.
c. telophase of mitosis.
d. telophase I of meiosis.
e. telophase II of meiosis.

Answer: This problem is tricky because the answers depend on how a cell is defined. In general, geneticists consider the transition from one cell to two cells to occur with the onset of anaphase in both mitosis and meiosis, even though cytoplasmic division occurs at a later stage.

a. 46 chromosomes, each with two chromatids = 92 chromatids
b. 46 chromosomes, each with two chromatids = 92 chromatids
c. 46 physically separate chromosomes in each of two about-to-be-formed cells
d. 23 chromosomes in each of two about-to-be-formed cells, each with two chromatids = 46 chromatids
e. 23 chromosomes in each of two about-to-be-formed cells

31. Four of the following events are part of both meiosis and mitosis, but only one is meiotic. Which one? (1) chromatid formation, (2) spindle formation, (3) chromosome condensation, (4) chromosome movement to poles, (5) synapsis.

Answer: (5) chromosome pairing (synapsis)

32. In corn, the allele *f′* causes floury endosperm and the allele *f″* causes flinty endosperm. In the cross *f′/f′* [female symbol] × *f″/f″* [male symbol], all the progeny endosperms are floury, but in the reciprocal cross, all the progeny endosperms are flinty. What is a possible explanation? (Check the legend for Figure 2-7.)

Answer: First, examine the crosses and the resulting genotypes of the endosperm:

Female	Male	Polar nuclei	Sperm	Endosperm
f′/f′	*f″/f″*	*f′* and *f′*	*f″/f″*	*f′/f′/f″* (floury)
f″/f″	*f′/f′*	*f″ and f″*	*f′/f′*	*f″/f″/f′* (flinty)